Hunting for Asymmetric Stops

Snowmass pre-pre-meeting, BNL, April 4th

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arXiv:1212. 4495

"Natural SUSY"

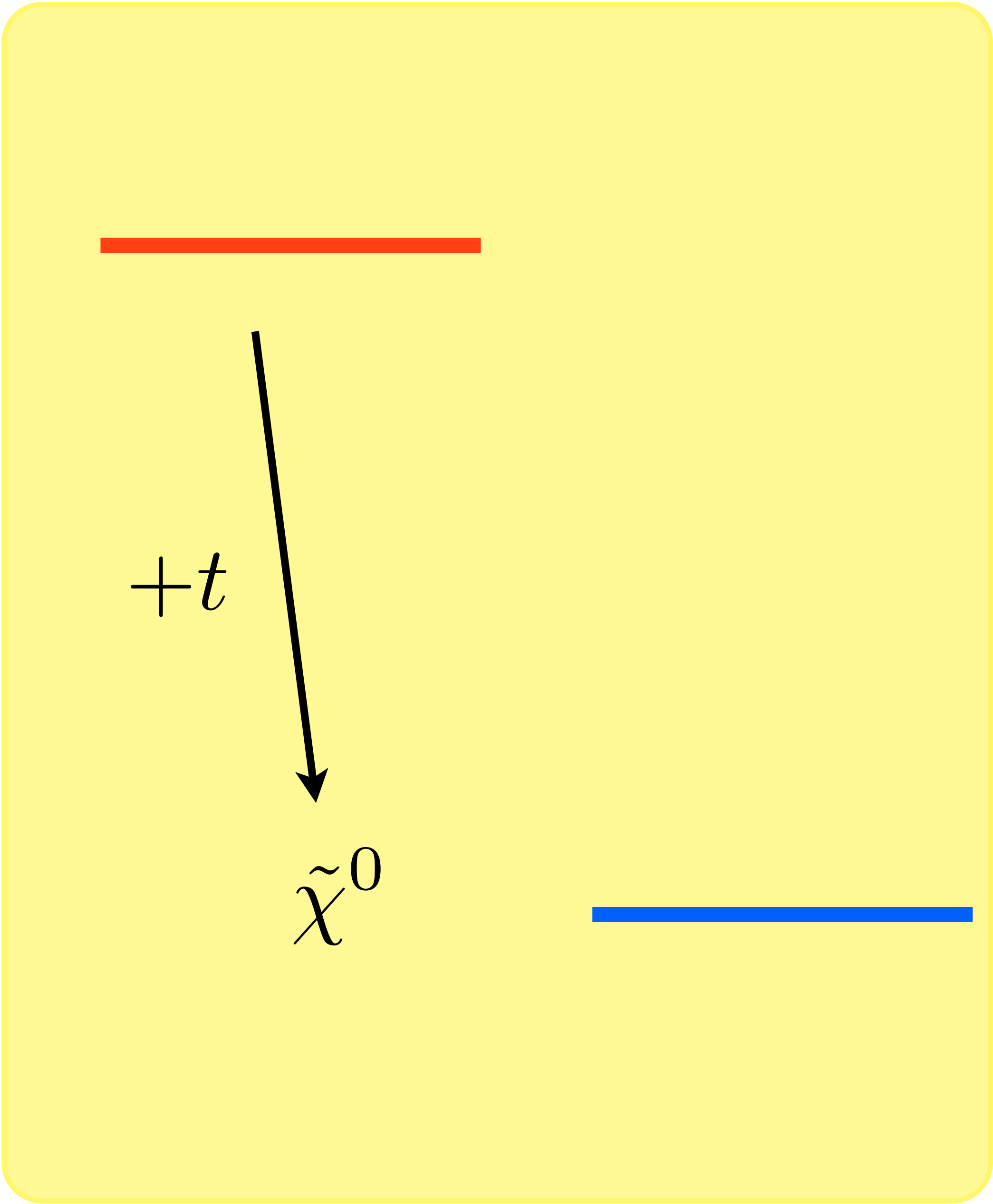
- Only a small subset of particles relevant to hierarchy problem at one-loop (Cohen, Kaplan, Nelson 1996; Brust, Katz, Lawrence, Sundrum, 2012; Papucci, Ruderman, Weiler, 2012)

- third generation squarks
- Higgsinos
- to a lesser extent, gluinos, winos and binos can't be too heavy
- remain agnostic about Higgs mass
- Searching for third generation squarks *top* priority

In so-called natural SUSY scenario, there are novel signatures of top squark pair production, precisely because of the Higgsino nature of the lightest neutralinos

Traditional searches for stops focus on decay

$$\tilde{t} \to t + \not{E}_T$$



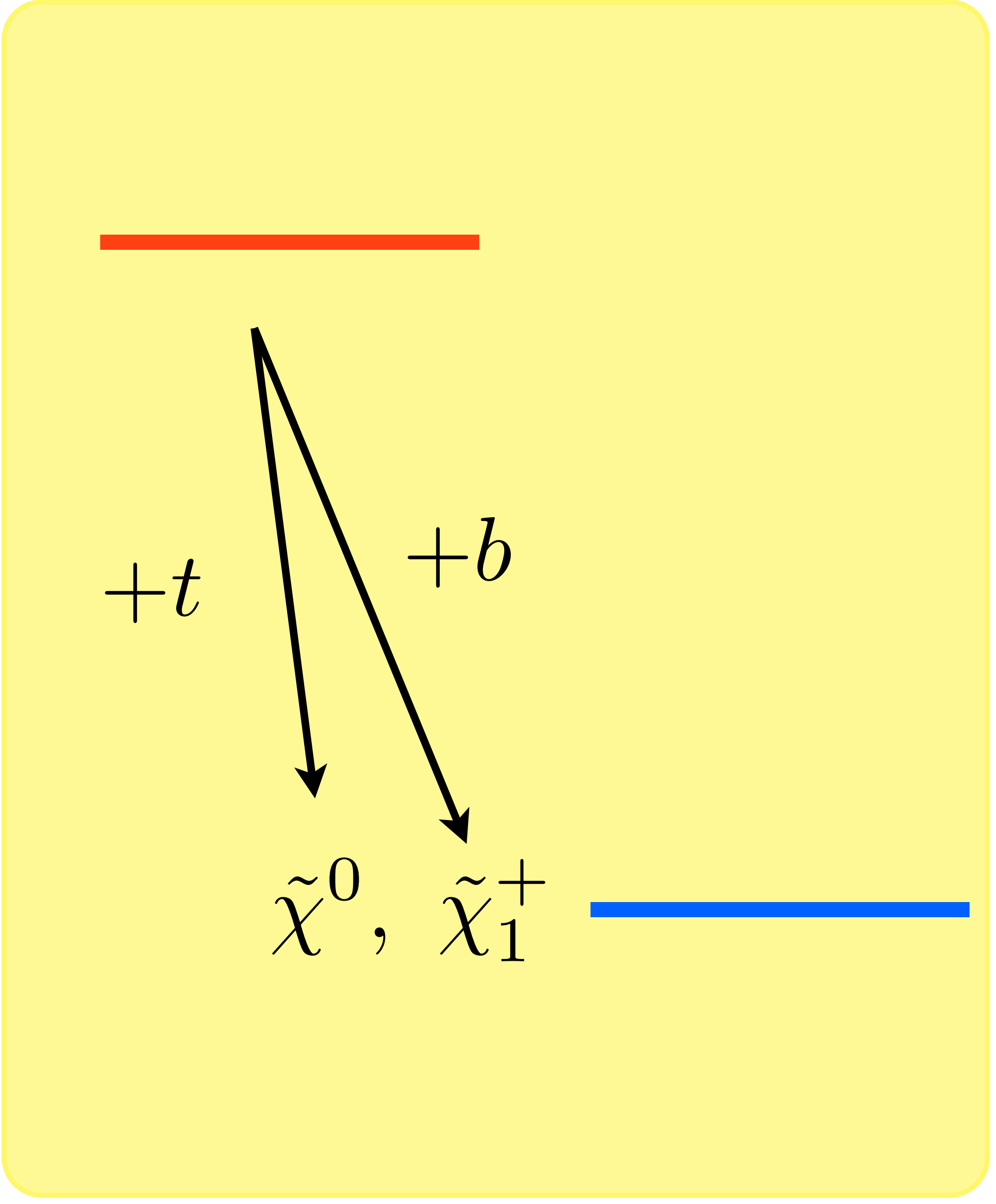
In so-called natural SUSY scenario, there are novel signatures of top squark pair production, precisely because of the Higgsino nature of the lightest neutralinos

Traditional searches for stops focus on decay

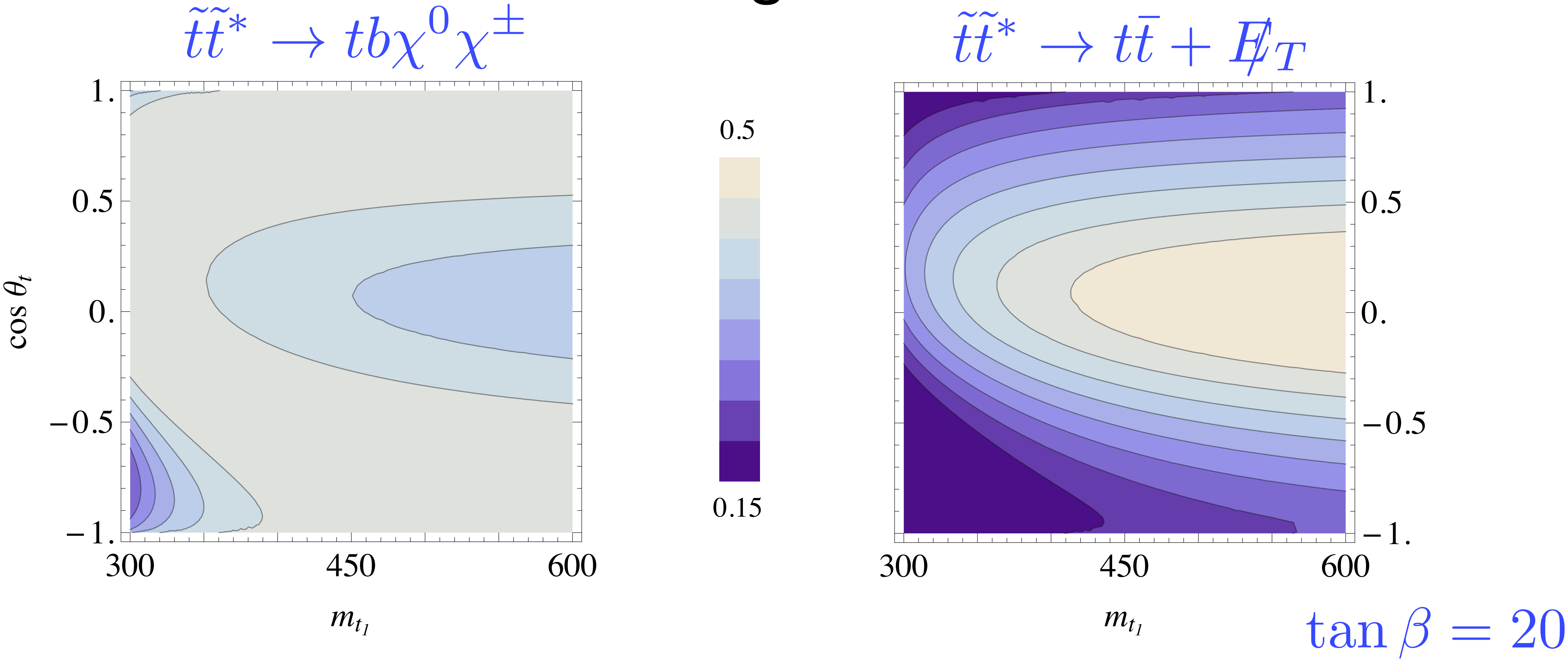
$$\tilde{t} \to t + \not{E}_T$$

But there is another decay

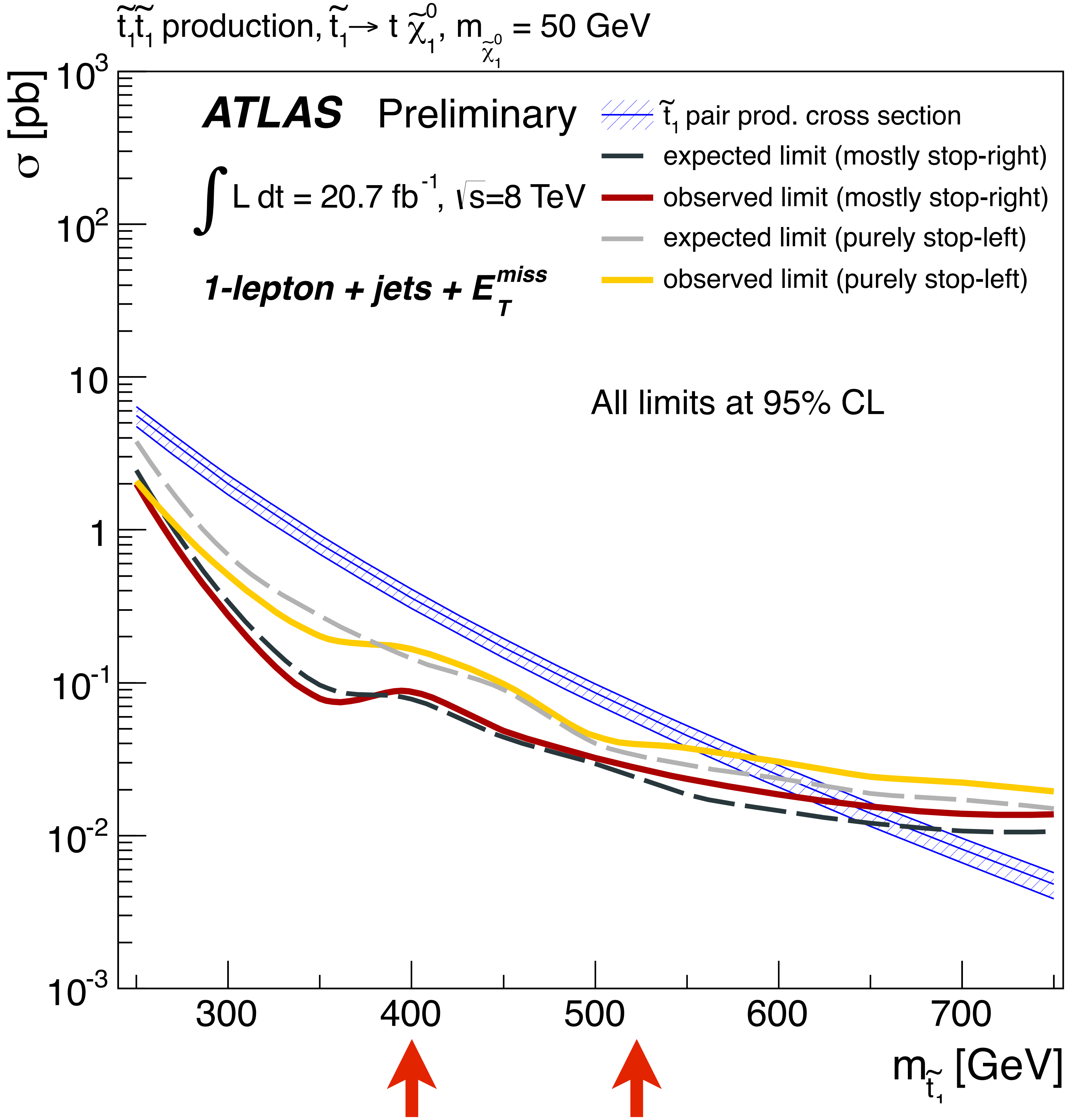
$$\tilde{t} \to b + \chi_1^+$$



Branching ratio



•stop pair production has sizable rate into *mixed* final state in regions of parameter space where the lightest stop $\tilde{t}_1$ has a sizable $\tilde{t}_R$ component



my "approximate limits" assuming BR=25%, 50% for RH stop decaying into this final state

Simplified signal model summary

$$pp \to \tilde{t}\ \tilde{t}^* + X$$

$t + \chi^0$

$b + \chi^0 + \mathrm{soft}\ l + \nu$

$\bar{t} + \chi^0$

$\bar{b} + \chi^0 + \mathrm{soft}\ l + \nu$

Final state signatures

“symmetric”	$t\bar{t} + MET$	ATLAS, CMS searches Bai et. al., 2012 Dutta et. al., 2013
	$b\bar{b} + MET$	ATLAS search; Cao et. al. 2012
“asymmetric”	$t\bar{b} + MET$	MG, J. Shelton, 2012

“asymmetric”

$t\bar{b} + MET$

$bl\nu$

Focus on leptonic decay of top quark

500 GeV stops:

- ~200 produced events at LHC 8 TeV with L=20 fb-1
- need to be efficient in object selection and analysis

Still, after imposing traditional cuts, S/B still not great, especially since statistics are low

Need to reduce bkg by ~ factor of 30

Dominant backgrounds after standard cuts (MET, mT, pT) are dileptonic tops and lepton-hadronic-tau tops

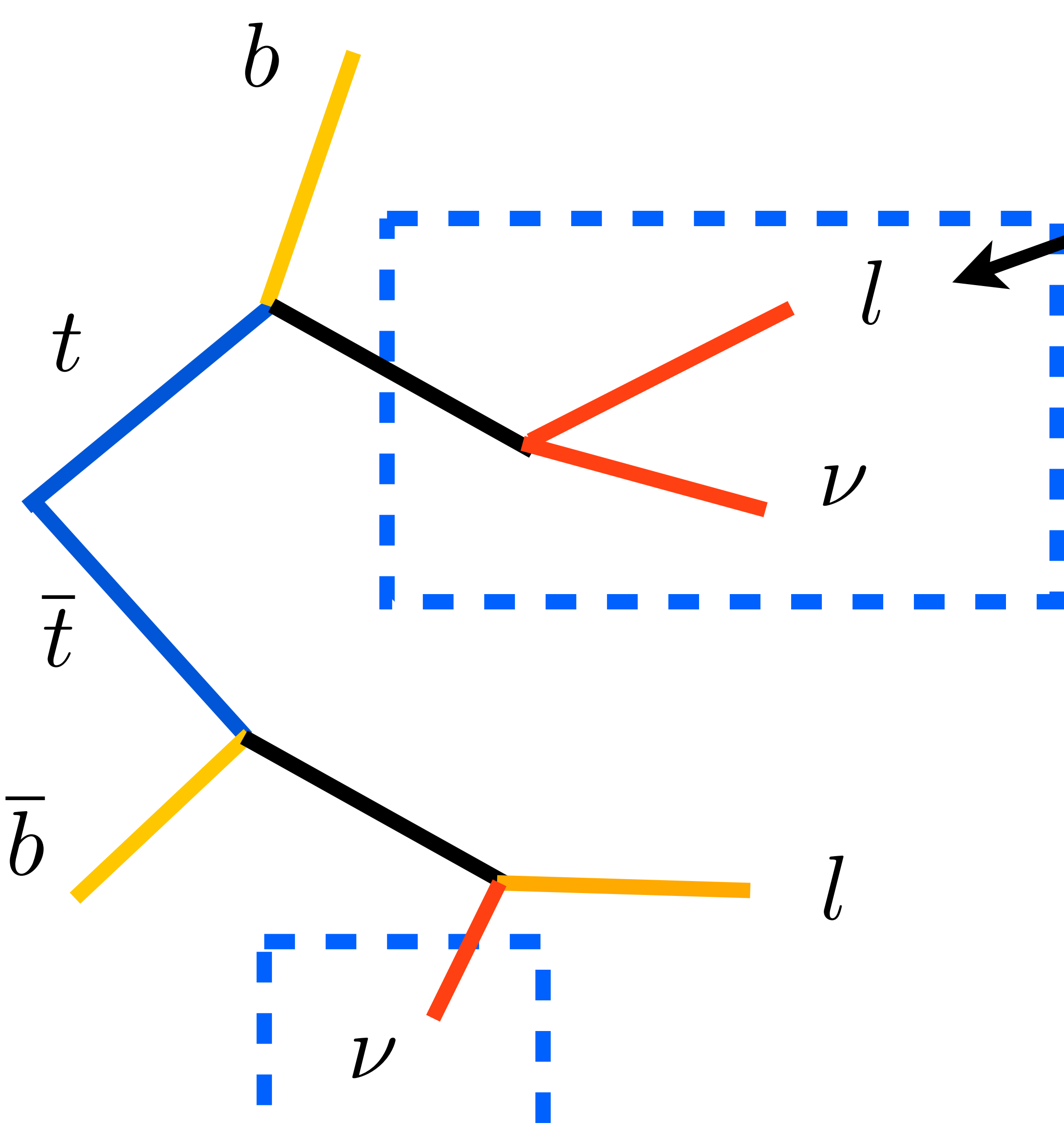
Propose a new search strategy, targeting simplified model "asymmetric decay"

- introduce a new kinematic variable, *topness*, crucial
- topness effectively suppresses the dominant backgrounds from top quark pair production, in single lepton final states

Topness

Once a lepton is lost, dileptonic background is an under constrained system.

Require *reconstructed center-of-mass energy is minimized*



soft or forward

missing W and missing neutrino
= 6 unknowns
constraints:
2 MET x,y
mass shell conditions:
1 W (for the lep+neutrino)
2 top quarks

Topness

replace minimization over 1 variable with over 4

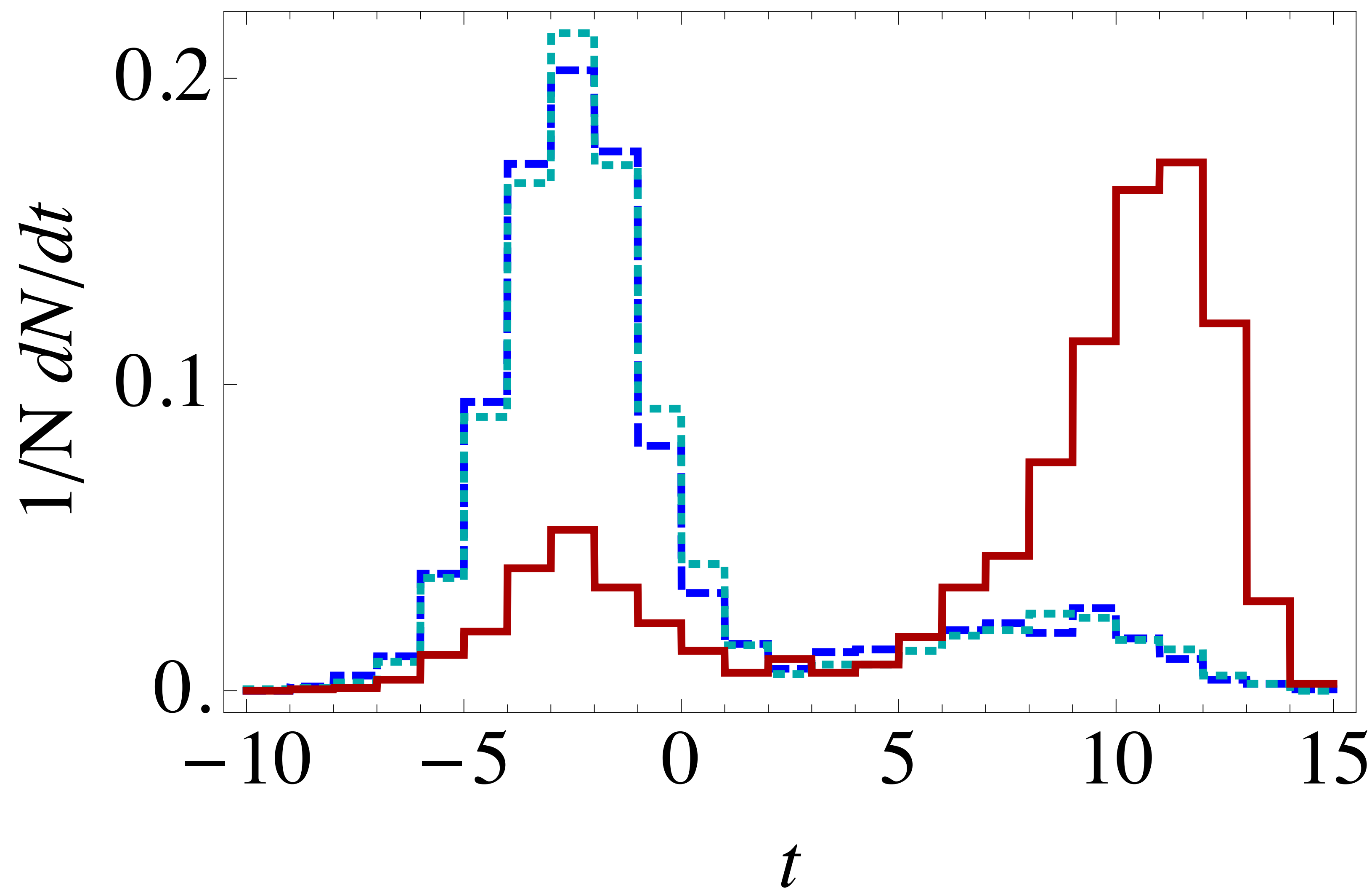
$$
\begin{aligned}
S(p_{Wx}, p_{Wy}, p_{Wz}, p_{\nu z}) &= \frac{(m_W^2 - p_W^2)^2}{a_W^4} \\
&+ \frac{(m_t^2 - (p_{b_1} + p_\ell + p_\nu)^2)^2}{a_t^4} + \frac{(m_t^2 - (p_{b_2} + p_W)^2)^2}{a_t^4} \\
&+ \frac{(4m_t^2 - (\sum_i p_i)^2)^2}{a_{CM}^4}
\end{aligned}
$$

presume COM energy = $2m_t$

a's should not be smaller than typical resolutions

aW=5 GeV, at=15 GeV, aCM=1 TeV

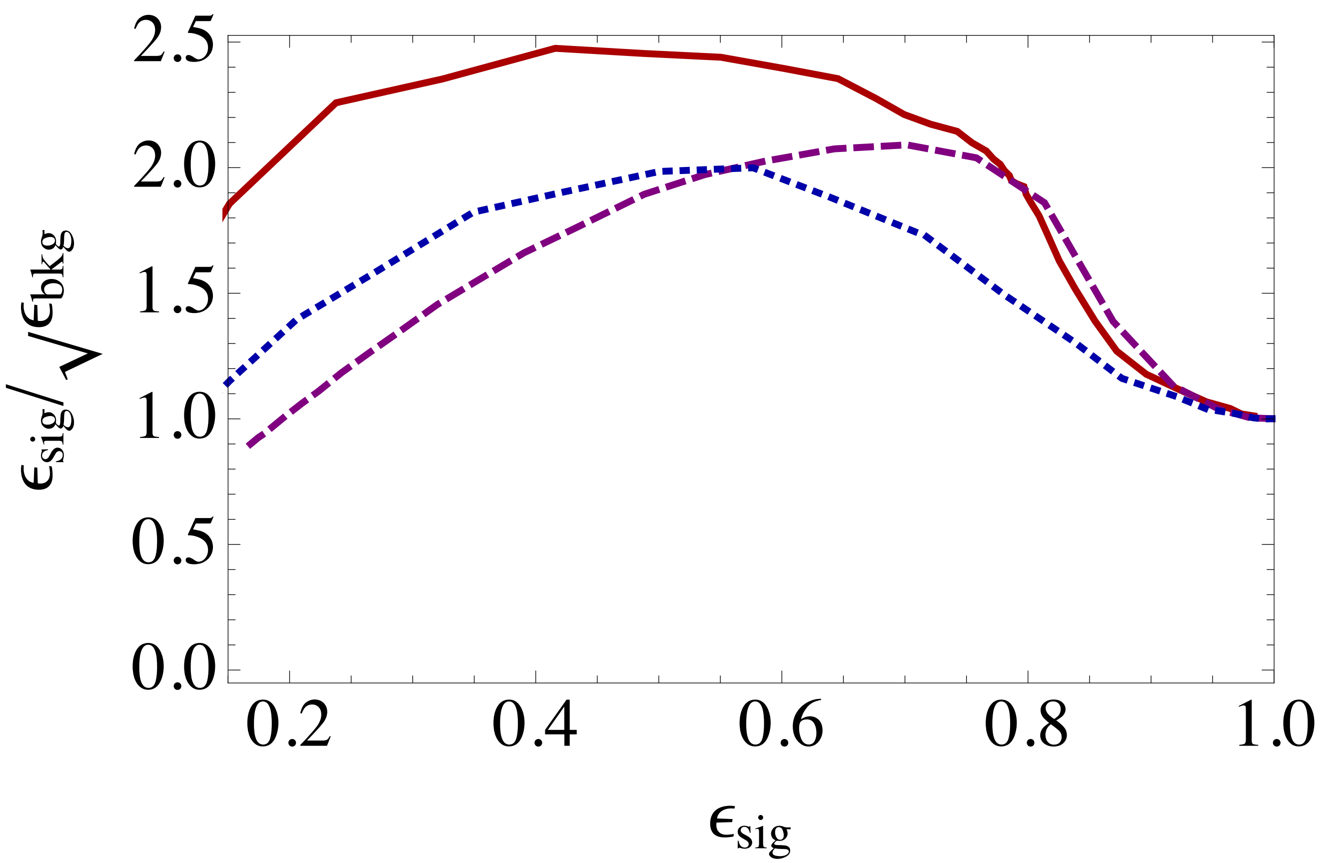
On events passing pre-selection:
Topness has good separation power



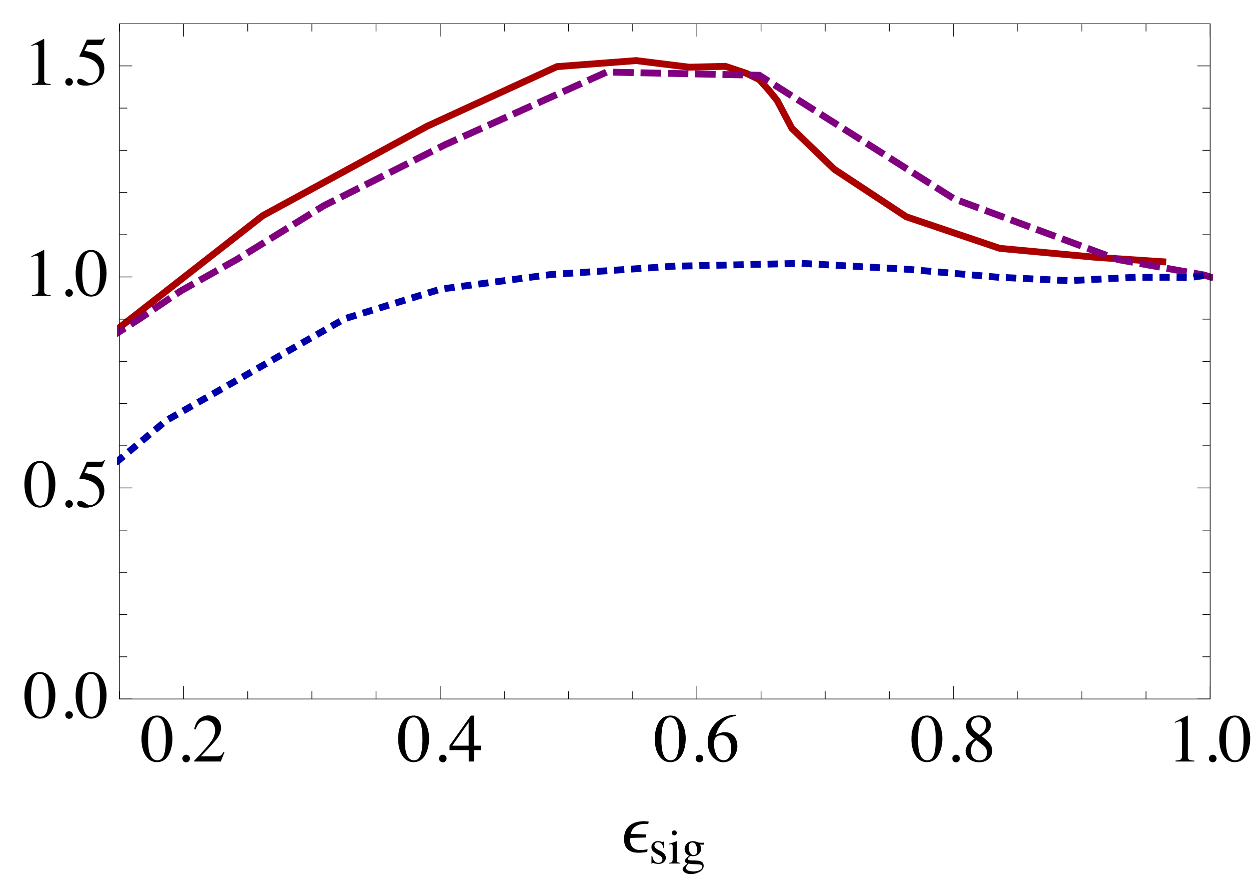
Signal (red) well-separated from tt background (blue/purple)

On events passing pre-selection: topness vs. other variables

asymmetric final state



symmetric final state



- for asymmetric final state, topness (red) outperforms MCT (blue) and MT2 (purple)
- for symmetric final state:
  - ➡comparable performance

Cut flow for reference model and significances (Poisson stat.)

$$\sqrt{s} = 8\ \mathrm{TeV}\ ,\ \mathcal{L} = 20\ \mathrm{fb}^{-1}$$

	σ_{sig}	$\sigma_{t\bar{t}}$	σ_{tW}	S/B	σ
preselection	2.1	54	4.3	0.036	1.2
lepton veto	2.1	44	3.4	0.044	1.3
$b_1\ p_T > 125$	1.5	22	1.6	0.065	1.4
$r_{pT} > -0.2$	1.5	21	1.5	0.066	1.4
$C < 3.0$	1.4	18	1.3	0.072	1.4
$t > 9.0$	0.98	0.82	0.38	0.82	3.5

big jump

topness

$$m_{\tilde{t}} = 500\ \mathrm{GeV}$$
$$m_{\chi} = 200\mathrm{GeV}$$
$$BR(tb + \not{E}_T) = 50\%$$

Other signal masses, best cuts and significances (Poisson stat.)

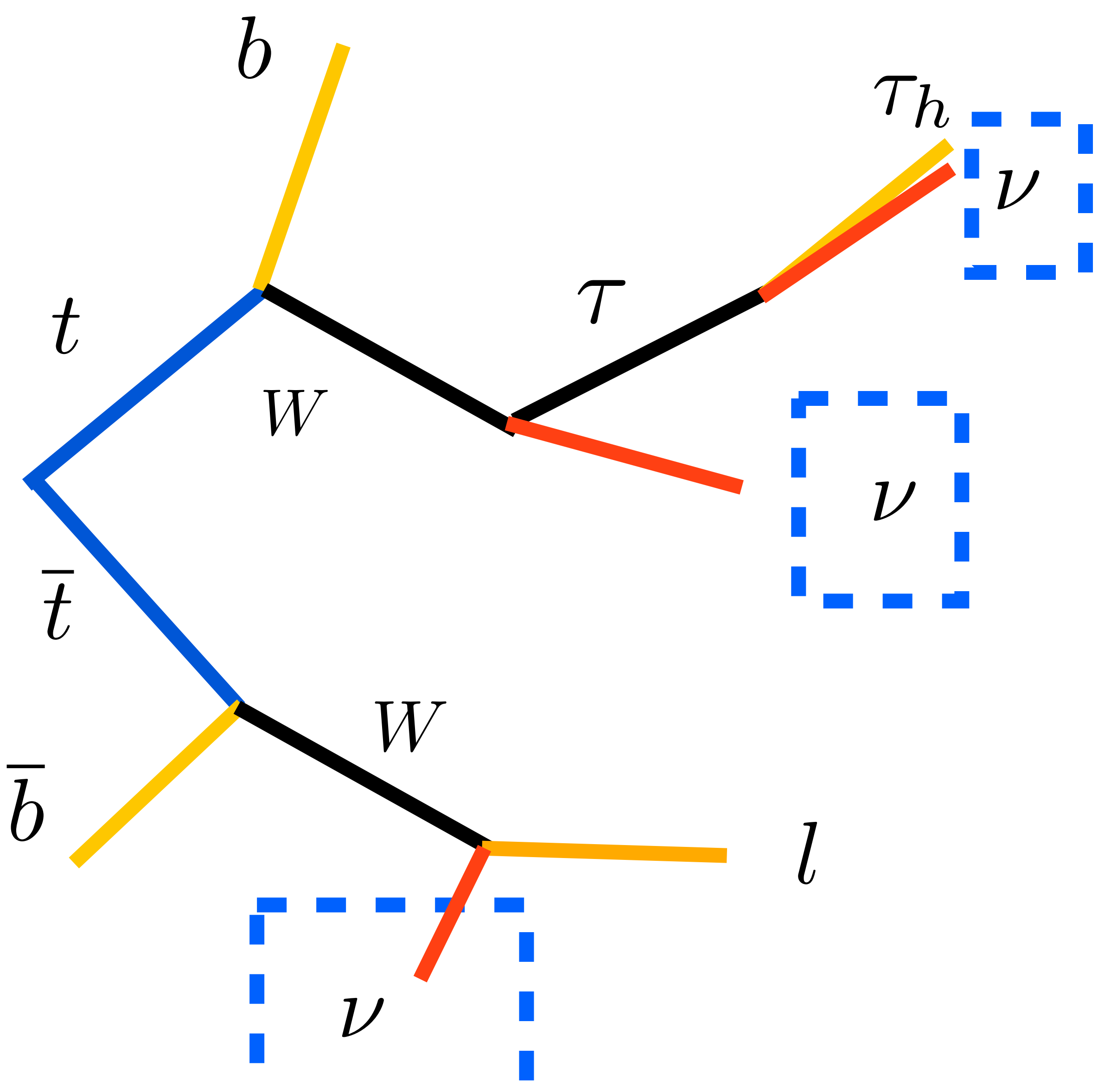
$$\sqrt{s} = 8 \text{ TeV} \ , \ \mathcal{L} = 20 \text{ fb}^{-1}$$

$m_{\tilde{t}}$	$m_{\chi_1^0}$	MET	$b_1\, p_T$	C	r_{p_T}	Topness	σ	S/B	σ_{sig} (fb)
400	100	200	150	3.5	-0.2	9.5	11*	3.1	2.0
400	200	150	75	2.5	0.0	8	2.9	0.38	1.2
500	100	250	175	3.75	-0.2	9.0	5.4	2.7	0.95
500	200	200	125	3.0	-0.2	9.0	3.5	0.82	0.98
600	100	300	225	4.25	-0.2	11.0	3.3	4.7	0.26
600	200	300	200	3.5	-0.2	10.5	2.5	2.6	0.23

- good reach achievable
- *topness* crucial

Topness: generalizations

Target tt leptonic- (hadronic) tau final states in collinear approximation



2 missing primary neutrinos
= 6 unknowns
1 more missing tau neutrino
= 1 unknown (collinear)
7 total unknowns
constraints:
2 MET x,y
mass shell conditions:
2 W
2 top quarks
= 6 constraints

Snowmass possibilities

- sensitivity at 13 TeV LHC ?
  - larger signal cross-section
  - larger background
  - tops more boosted, expect separation power of topness to be weakened
  - in our study MadGraph>Pythia level only
    - no detector simulation, no pileup

Conclusions

- stops in natural SUSY spectra will generically have large branching fractions to the mixed final state

$$\tilde{t}\tilde{t}^* \to tb + \not{E}_T + \text{soft}$$

- this final state dilutes rate into traditional search channel $\tilde{t}\tilde{t}^* \to t\bar{t} + \not{E}_T$

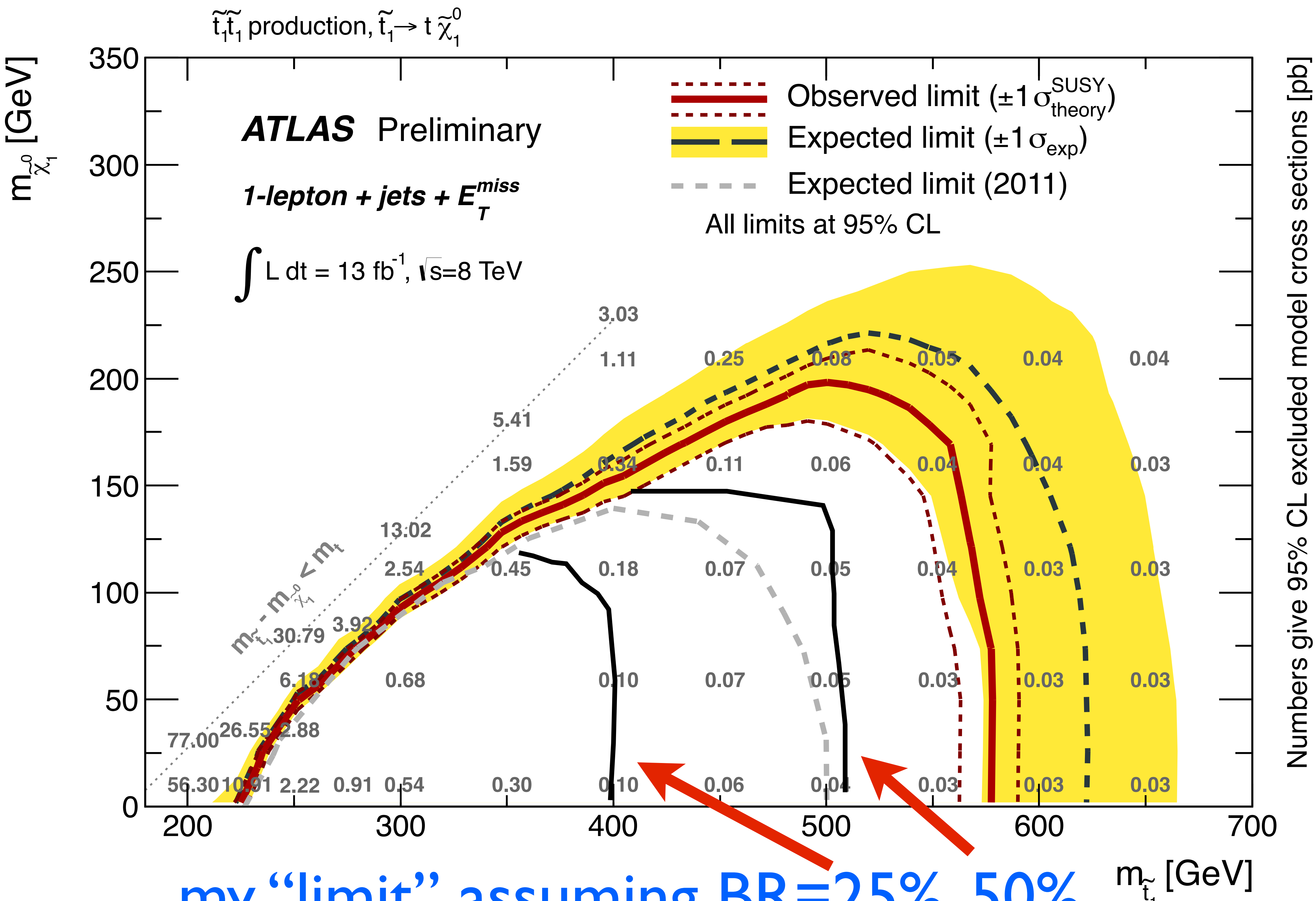
- we propose a new search strategy

- good reach achievable with novel variables introduced, such as *topness*

- should search for stops in all (tt,bb,tb) channels

Backups

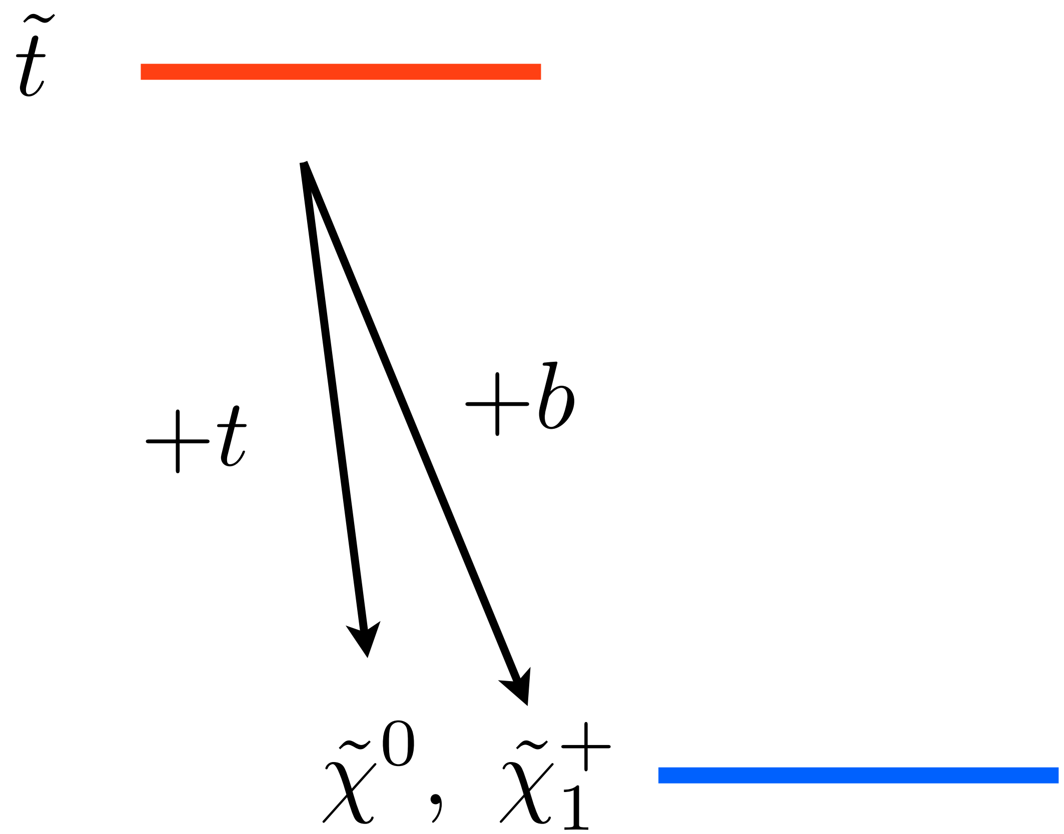
older ATLAS stop search limits, 2012 Dec. conf. note



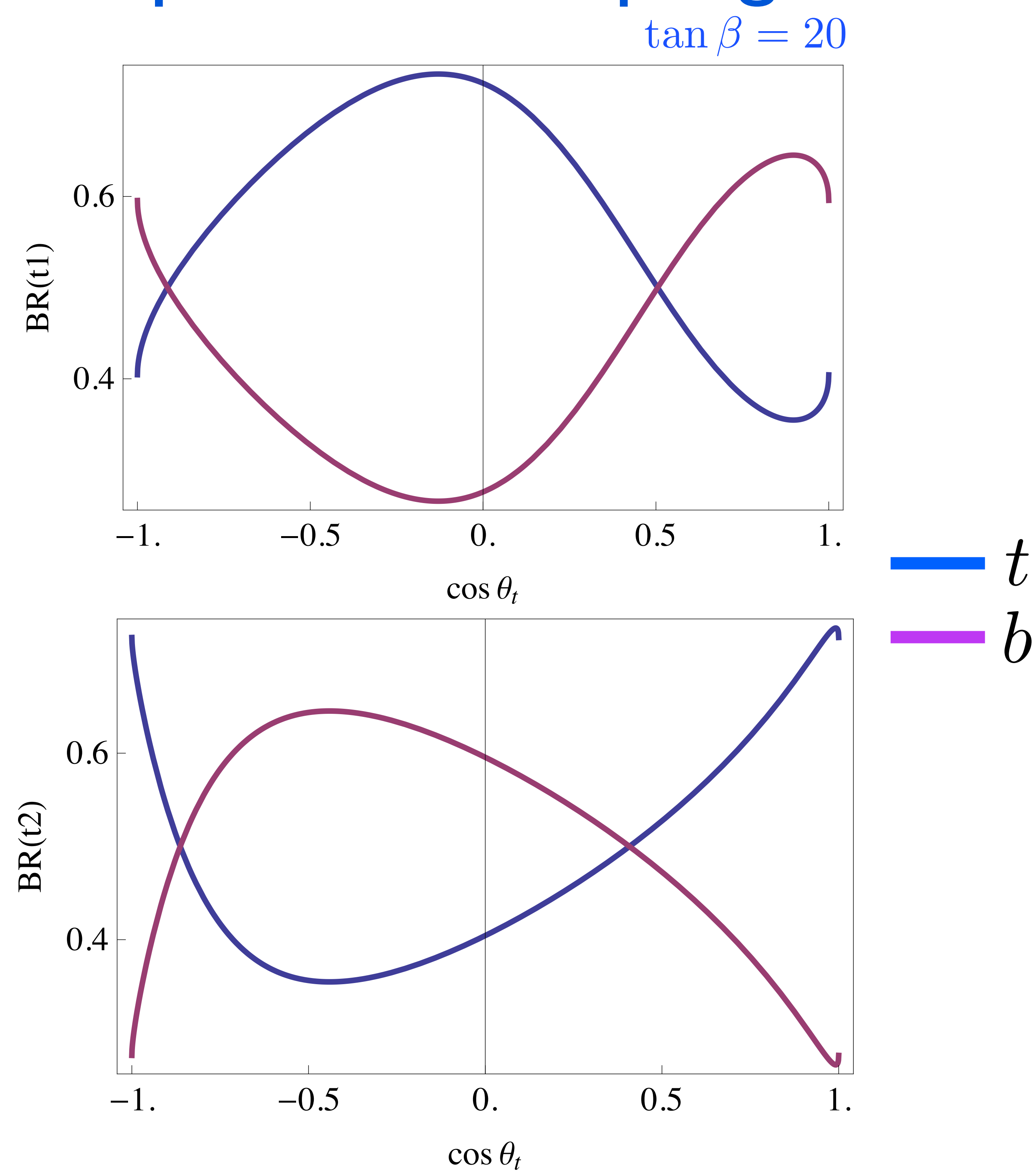
my "limit" assuming BR=25%, 50% into this final state

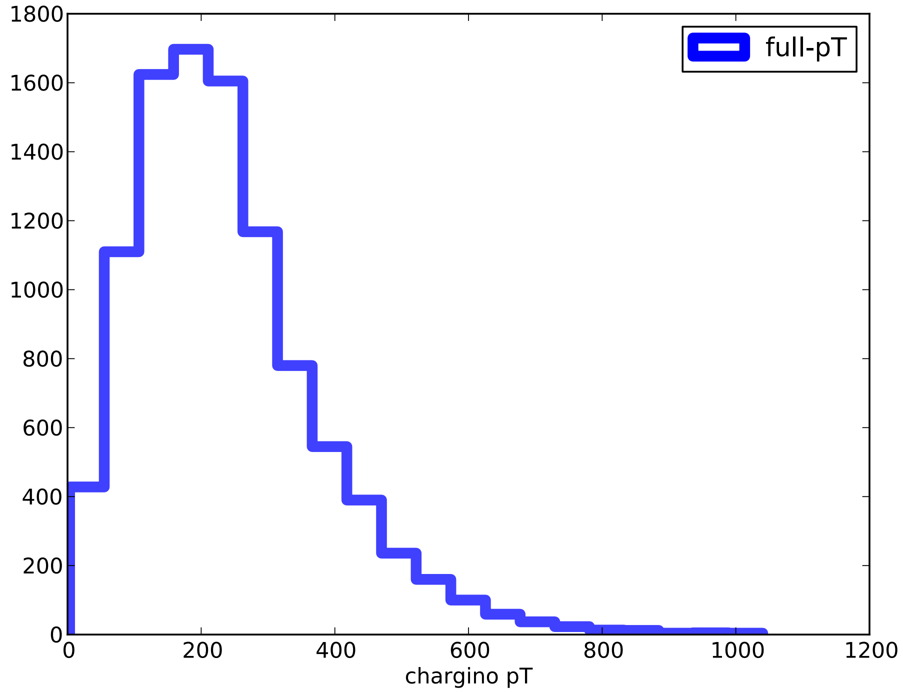
Spectroscopy

decay through SUSY top Yukawa couplings



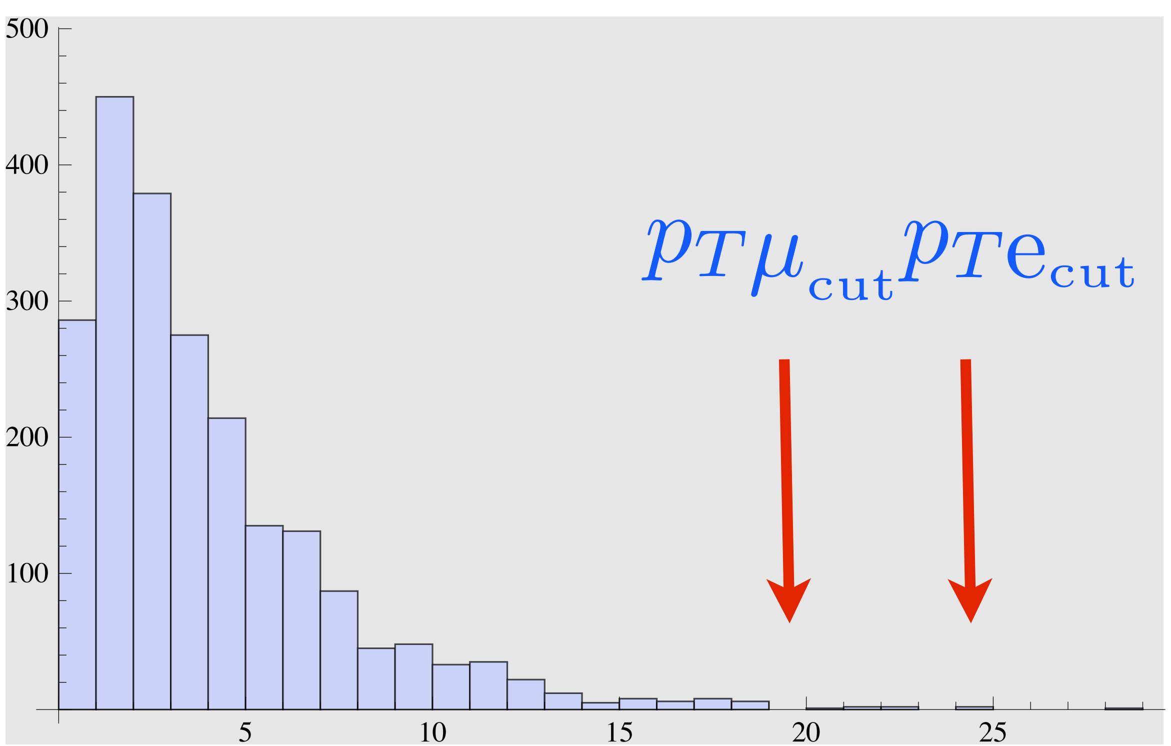
Degenerate neutral and charged Dirac fermions





Chargino is not too boosted

Chargino has prompt decay, but visibles too soft

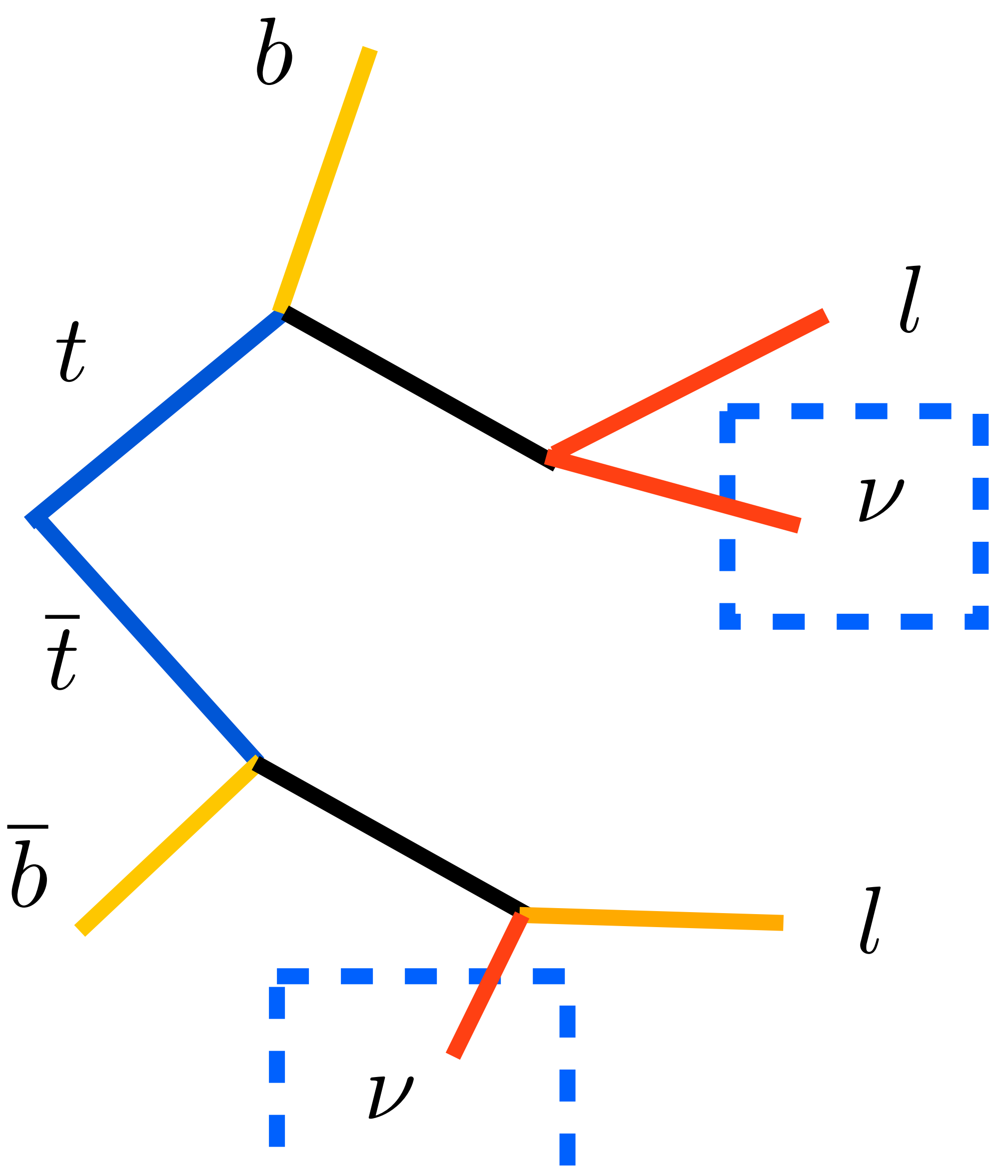


$$\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 + l^+, q$$

$p_{T,l}(\mathrm{GeV})$

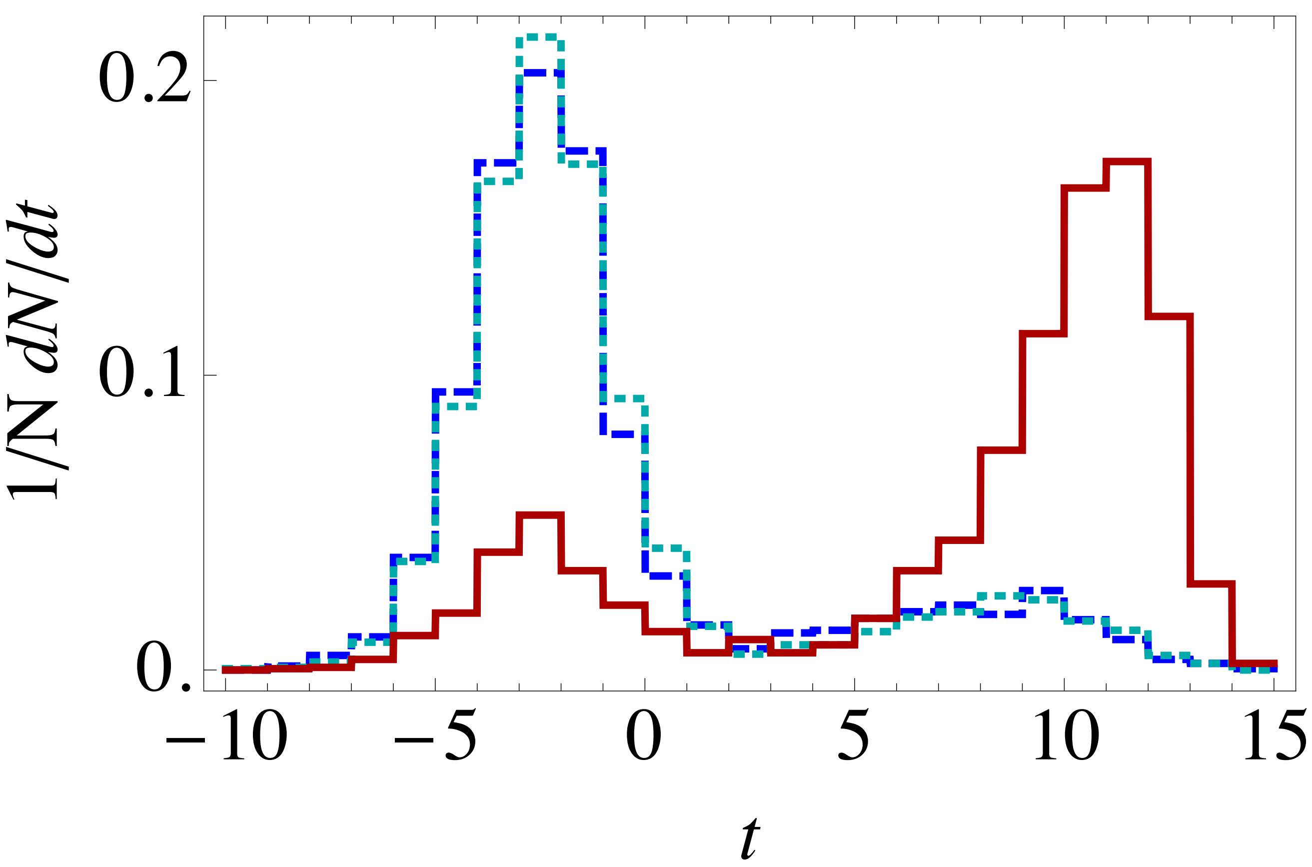
Topness

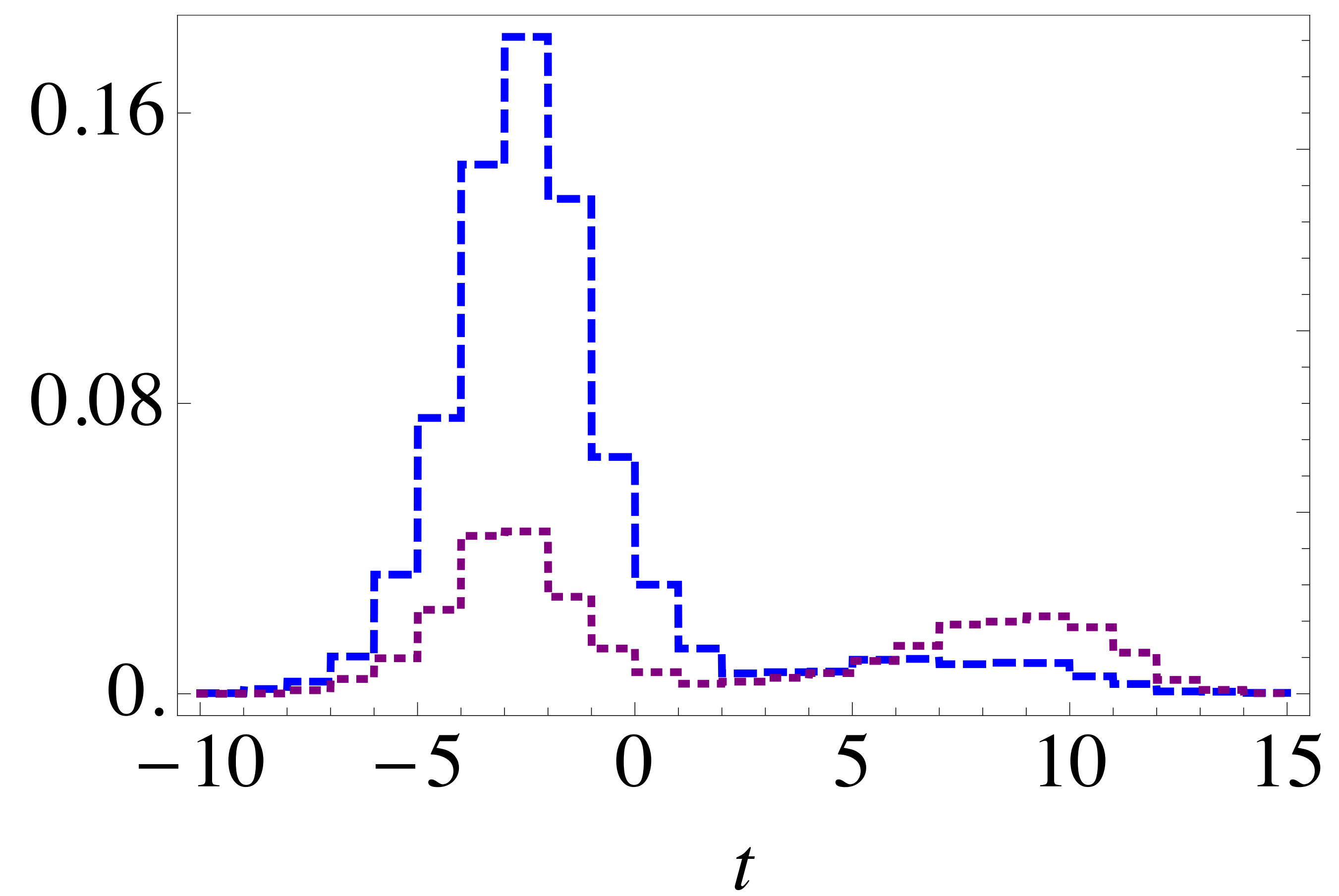
For a *dileptonic* top, where both leptons are identified, there is enough information and mass shell conditions to reconstruct the tops



missing 2 neutrinos
= 6 unknowns
constraints:
2 MET x,y
mass shell conditions:
2 W's
2 top quarks

On events passing pre-selection:
Topness has good separation power





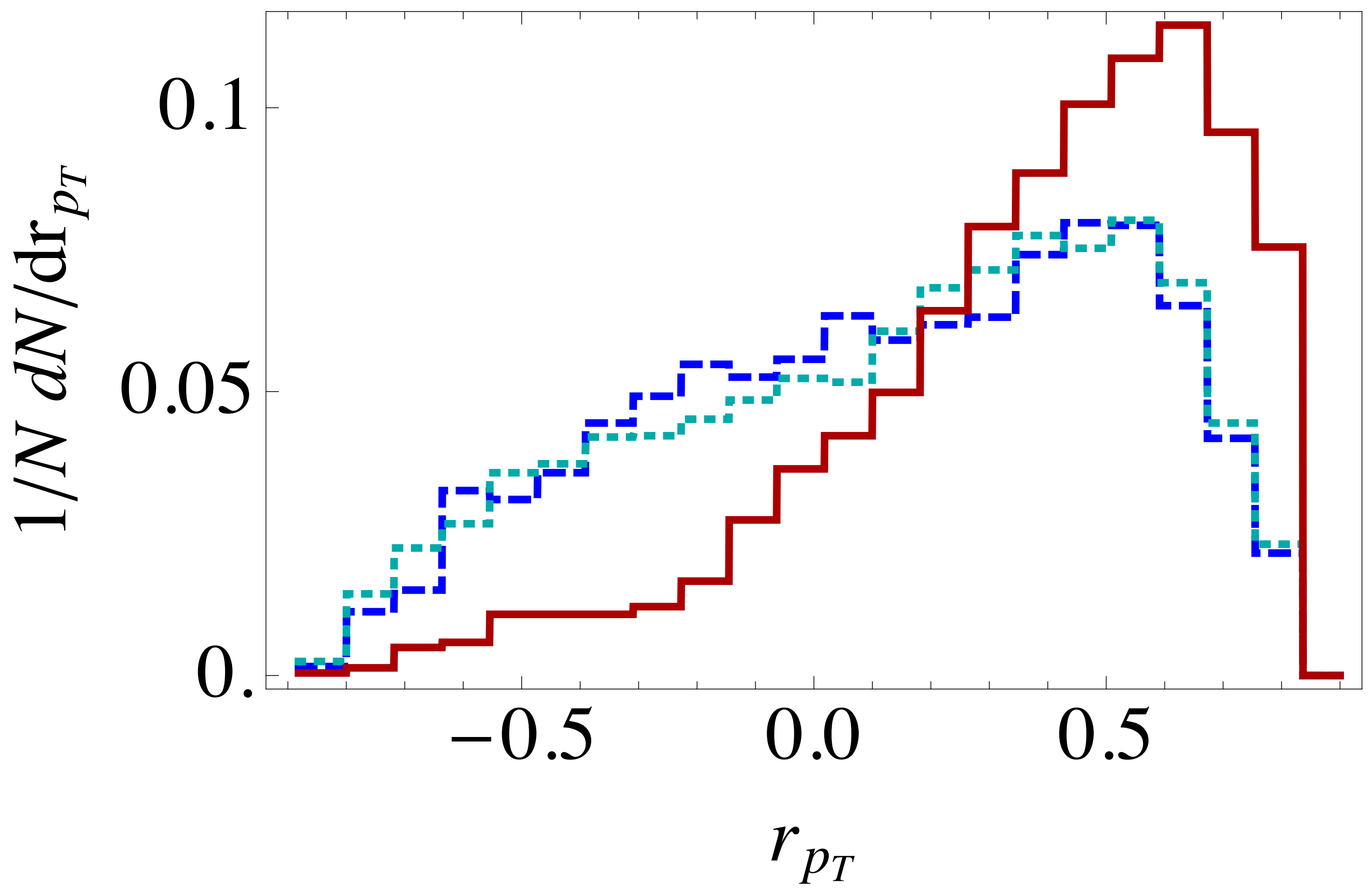
- LHS: signal (red) well separated from tt background (blue/purple)
- RHS: 2 truth b's vs. 1 truth b for tt
  - in future with large statistics, can further reduce background by requiring 2 b-tags

Topness described

- value of S at minimum quantifies how well event can be reconstructed according to the dileptonic top hypothesis
- inputs are 2 or 3 jets (depending on #b's), 1 lepton, and MET
- if the event has two b's use those, summing over both pairings of b-jets with reconstructed W's
- if the event has only 1 b, sum over both pairings of the b-jet and a second jet with reconstructed W's, where for the non-b jet we cycle through the two highest pT (non-b) jets

$$\boxed{t = \ln(\min S)}$$

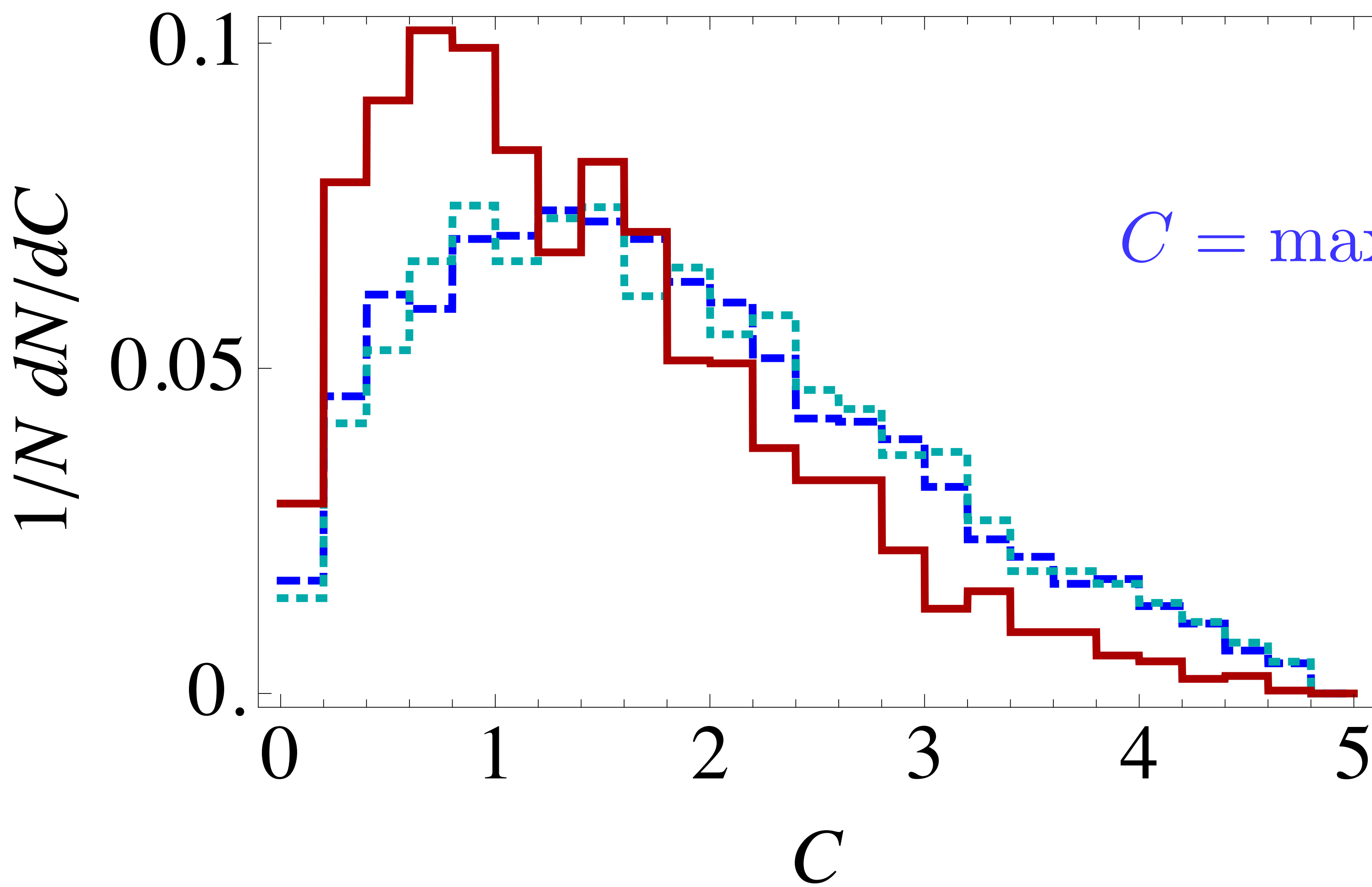
On events passing pre-selection: r_{pT}



$$r_{p_T} = \frac{p_{Tb_1} - p_{T\ell}}{p_{Tb_1} + p_{T\ell}}$$

- signal (red) more "asymmetric" due to higher pT b produced directly from stop decay

On events passing pre-selection: C



$$C = \max\left(\left|\Delta\eta_{j_1, j_2+\ell+\not{p}_T}\right|, \left|\Delta\eta_{j_2, j_1+\ell+\not{p}_T}\right|\right)$$

- stops (red) more central than top quark pair production due to difference in kinematics of production (Han, Katz, Krohn, Reece, 2012)

Event generation

- normalize signal (Falgari et. al., 2012), tt (Beneke et. al. 2012) and tW (Kidonakis,2012) processes to inclusive NLO+N(N)LL 8 TeV cross-sections

- Events are generated in Madgraph, showered in Pythia and clustered in FastJet using the anti-k_T algorithm with R = 0.4

- In generating tW+1j events, we forbid tt events from contributing when the momentum in one of the internal top propagators lies close to mass shell (Frixione et al., 2008; Alwall et al.2008)

Event generation: lepton, hadronic tau isolation

- Leptons are declared isolated if the scalar sum-pT deposited in a cone of radius R_iso=0.2 around a lepton is less than 0.2 times the lepton pT

- We identify hadronic taus when the scalar sum-pT deposited in a cone of radius R_iso=0.2 around the visible hadronic tau is less than 0.6 times the tau pT

  These criteria for tau are tuned to yield an efficiency of approximately 50%, comparable to experimental tau working points, on hadronic taus with pT>20 coming from the W in tt events.

- we assume a uniform probability 0.7 to tag a b-jet with pT > 20 GeV and rapidity <2.5.

- We generated more than enough events to ensure our final results are insensitive to statistical fluctuations in our Monte Carlo simulations